

X-ray radiography of fracture flow and matrix imbibition in Topopah Spring Tuff under a thermal gradient

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Introduction. Understanding and predicting the performance of a high-level nuclear waste repository requires knowledge of how water flows through heated, unsaturated, fractured rock. The distance that water can travel during gravity driven fracture flow is controlled by several factors, including the saturation of the matrix, the fracture aperture, the capillary properties of the matrix, and the temperature of the rock. We have performed a series of experiments to investigate fracture flow and fracture-matrix interactions under a thermal gradient using x-ray radiography to image some of the above factors and processes.

Description of work. Tabular blocks (14 x 10 x 2.5 and 23 x 15 x 2.6 cm) of densely welded Topopah Spring tuff (~10% porosity) containing induced tensile fractures (held open with 25 μm gold shims) were prepared from a larger outcrop sample from Fran Ridge, NTS. Water (doped with KI to enhance contrast) was ponded on the top of the upper fracture surface and allowed to flow down the fracture while x-ray radiographs were periodically taken to image water movement in the fracture and matrix. Difference imaging permits the calculation of spatial and temporal variations of saturation in the matrix. The tests conducted include monitoring of fracture flow and matrix imbibition (1) at 23°C in an initially dry sample followed by heating from below, (2) under a thermal gradient of ~111°C at the bottom and ~28°C at the top, (3) with a thermal gradient of ~148°C at the bottom and ~80°C at the top, followed by a period of cooling.

Results. Each experiment is similar in that flow down the fracture is rapid (flow down entire length of fracture in minutes) and is followed by slower lateral imbibition into the matrix. In the case of heating from below after saturation, dryout is evident along the fracture, followed by the development of highly attenuating regions (indicative of increased saturation) that are parallel to the heat source (heated from below). When the sample is heated prior to ponding, flow down the fracture is rapid until the boiling zone is reached, at which point flow stops. A roughly circular region of high attenuation develops that is interpreted as a region where boiling has occurred. It is possible that this region indicates the development of an isothermal region where boiling is actively occurring or a region of evaporation where there is deposition of KI crystals. When the sample is cooled, fracture flow resumes and extends through to the bottom of the fracture.

Conclusions. We are able to visualize phenomena related to fracture flow and matrix imbibition during experiments at a variety of conditions and quantitatively calculate saturation within the matrix. Preliminary results indicate that under these conditions it is difficult for water to penetrate a region where temperatures are above boiling, but that water can penetrate this region upon cooling. These results provide important input needed for understanding coupled thermal-hydrological-chemical processes and models of repository design based performance.

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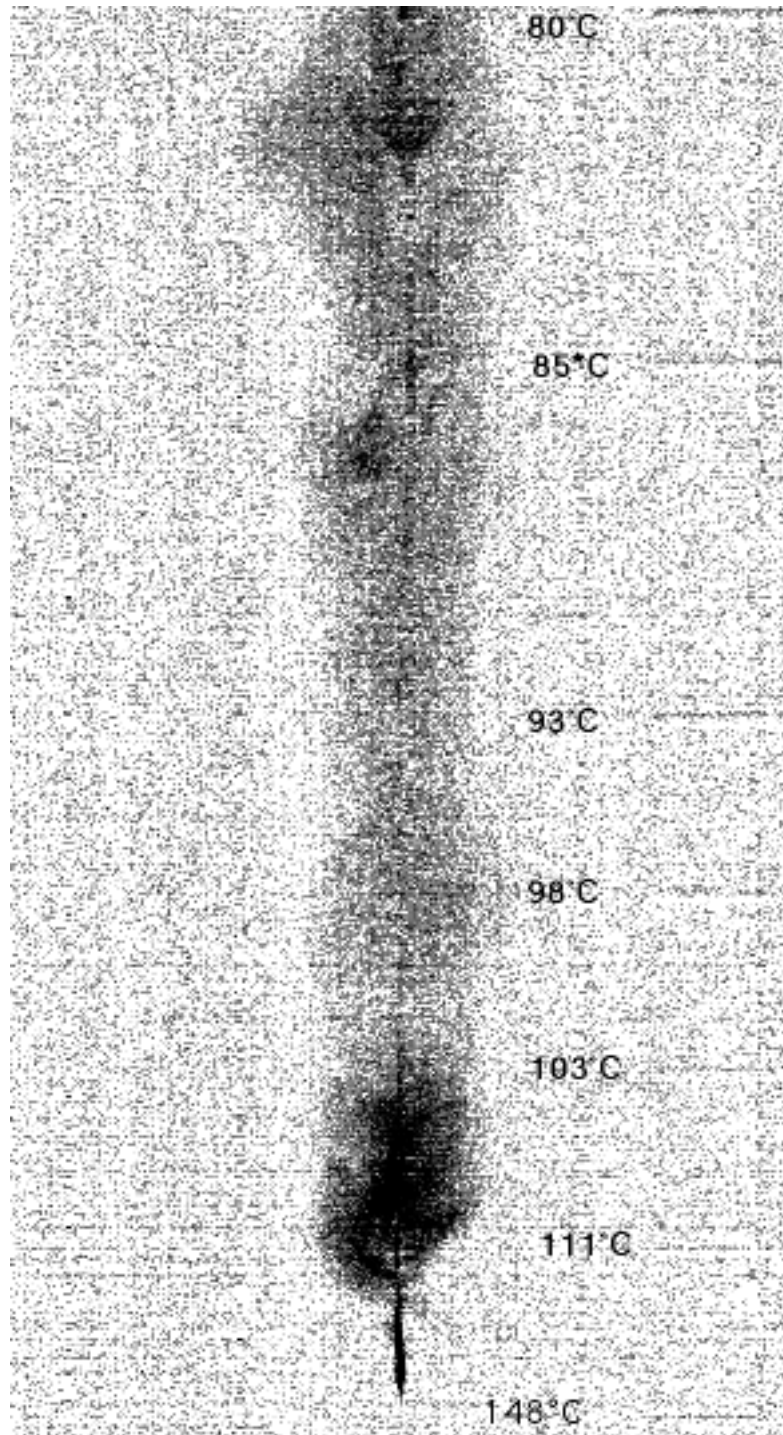


Figure 1. X-ray radiograph (difference image) of fracture flow 7.25 hours after water was ponded on top of the sample. The fracture is approximately in the center of the field of view. Darker shades indicate relatively high x-ray attenuation and the presence of water, while lighter areas correspond to lower attenuation and relatively dry areas. Temperatures shown (°C) are temperatures at the tips of the thermocouples (barely visible). Sample is 23 cm high. The dark region in the fracture below the boiling zone is probably crystalline KI deposited from solution. KI is added to the water as a contrast agent.